A Unified Model of the High-Ionization Nuclear Emission-Line Region in Active Galactic Nuclei

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論文内容要旨

It has been often considered that emission-line regions around active galactic nuclei (AGN) are *photoionized* by the non-thermal continuum radiation from central engines. However, this photoionization scenario has been sometimes confronted with several serious problems and then other new mechanisms (e.g., shock heating) have been proposed. The reason for this is attributed mainly to our poor knowledge of *structural* properties of the emission-line regions. One of the spectacular emission lines observed in AGN is so-called coronal lines which are emitted from highly ionized heavy-element ions such as N^{+4}, Fe^{+6}, and Fe^{+13}. Since these high-ionization lines should be related intimately to the high-energy photons emitted from the central engines, it is expected that they provide us very important information on the ionization mechanisms in AGN. In this thesis, in order to investigate whether or not the photoionization is really responsible for the ionization of gas clouds around AGN, we have made observational, statistical, and theoretical analyses of high-ionization nuclear emission-line regions (HINERs) in AGN.

First we have collected optical spectroscopic properties of a sample of 111 Seyfert galaxies compiled from the literature and our own spectroscopic study. These data are utilized to elucidate physical properties of the HINERs. From this analysis, we find the following three important results. (1) The fraction of Seyfert nuclei with the HINER is nearly the same (~60%) between the type 1 and the type 2 Seyferts (hereafter, S1s and S2s, respectively). We also find the significant correlation between [FeⅦ] λ6087／[OⅠ] λ6300 and [OⅢ] λ5007／[OⅠ] λ6300 for *all* the types of Seyferts. Therefore, it is suggested that a part of the HINER is associated spatially with the narrow-line region (NLR) and thus its characteristic distance is estimated to be r ~100 pc where r is the radial distance from the galactic nucleus. (2) On the other hand, we find that the [FeⅦ]／[OⅢ] intensity ratio is higher by one order of magnitude on the average in the S1s than in the S2s. This suggests strongly that a major part of the HINER emission cannot be observed in the S2s. Taking the current unified models of AGN into account, we may conclude that the most likely place is the inner wall ($r < 1$pc) of dusty tori because the most parts of the inner wall may be hidden from our line of sight by the torus itself for the S2s. Since the critical densities of most high-ionization lines are comparable to those in the dusty tori (e.g., ~ 10^{7-8} cm^{-3}), it is reasonably understood why the inner wall provides the major contribution to the HINER emission. (3) Another possible site for the HINER is the low-density (e.g.,~ 1 cm^{-3}) interstellar medium at r~1kpc because this low density makes it possible to create the HINER though the high-ionization photon density may be also low. Contrary to this theoretical expectation, no very extended HINER has been detected for these decades. However, we have discovered a very extended HINER (r ~ 1kpc) in the Seyfert galaxy Tololo 0109-383. Though the frequency of occurrence of the very extended HINER appears to be very low, we have verified its presence spectroscopically. Taking all the above properties of the HINER into account, we conclude that *there are three kinds of HINER*; 1) the torus HINER ($r < 1$pc), 2) the HINER associated with the NLR (10 pc $< r <$ 100pc), and 3) the very extended HINER ($\sim$ 1 kpc). Since there are large scatters in both the [FeⅦ]/[OⅢ] intensity ratio and FWHM([FeⅦ])/FWHM([OⅢ]) in all the types of Seyferts, the contribution from the three kinds of HINER may be different from object to object.

We compare the observational properties of the HINER with our new photoionization models. First, in order to find optimal properties of the HINER, we have made photoionization model calculations for a *single cloud*. We find that the optimal properties of the HINER are log U ~ -2--1.5 and $n_H \sim 10^{4-6.5}$(cm^{-3}). These parameter ranges suggest the picture that the HINER is a cool gas ($T_e \sim$ a few$\times 10^4$K and $n_e \sim 10^6$cm^{-3}) photoionized by the central non-thermal continuum emission. However, the single cloud model have a very serious problem; i.e., iron abundance is required to be ten times as high as the solar value to explain the observed [FeⅦ]/[OⅢ] intensity ratios. Second, we have performed photoionization calculations for two-component cloud models in which one cloud corresponds to the NLR and the other corresponds to an ionized cloud in the torus. It is known that the covering factor of the torus is usually high, e.g.,$\sim$0.9. Further, because of the higher electron density (e.g., $\sim 10^{7-8}$cm^{-3}) with respect to that in the NLR (e.g.,$\sim 10^{3-4}$cm^{-3}), the torus emission contributes to the majority of optical emission lines, in particular to the higher-ionization emission lines. We find that if the torus emission contributes to$\sim$10% of the NLR emission, we can explain the observed high [FeⅦ]/[OⅢ] intensity ratios without invoking the *unusual* overabundance of iron.

In summary, we have explored the most probable structure of the ionized regions around AGN. Comparing the observational properties of the HINER with our new two-component photoionization models, we have established that the photoionization scenario can explain the observations without invoking any unusual assumption.

論文審査の結果の要旨

活動銀河核は，分光学的に，銀河の中心核が示す特徴のため，特に認識されるようになった。その認識は既に1940年代後半に始まるが，銀河の生成と進化の問題を解決するため重要な手掛かりが得られるとの理解により，近年頻繁に，特に研究対象として取り上げられるようになっている。しかし，これまでの研究は特定の活動銀河核を扱っている場合が多く，一様でしかも多数のサンプルによる研究に欠ける憾みがあった。

村山卓提出論文では，活動銀河核の高電離状態の電離ガス領域の構造的性質を明らかにし，光電離モデルを検証するために，高電離輝線について観測的，統計的，理論的解析を行った。高電離輝線は低電離輝線に比べ，高い電離エネルギーを要するため，構造的に低電離輝線とは違った場所から出ている可能性が大きい。111個のセイファート銀河の可視光スペクトルデータの解析における重要な結果は，高電離輝線領域を狭輝線領域に付随する成分，より内側のトーラス内壁に付随する成分，さらに1kpc程度の星間空間まで広がった成分の３つに分けたことである。特に，トーラス成分は，１型セイファート銀河では２型セイファート銀河に比べ系統的に[FeⅦ]6087/[OⅢ]5007 強度比が大きいという発見から帰着されたが，これは活動銀河核統一モデルの描像に良く合致する結果である。又，広がった高電離輝線領域としては，Tololo 0109-383 における高電離輝線が空間的に1kpc程度広がっていることを初めて明らかにした。さらに，これらの異なった高電離輝線成分を考慮し，光電離モデルが観測データを説明出来るか検証を行った。狭輝線領域とトーラスそれぞれについて電離モデルを計算し，それを組み合わせるという二領域モデルで観測データを説明している。従来の一領域モデルでは，元素組成を太陽組成から大きく変更したり，ショック加熱などの別のメカニズムを考えることで観測を説明しようとする試みがあったが，この二領域モデルでは標準的な光電離モデルの枠組みで観測を再現することが出来た。これらの研究において得られた新知見は，活動銀河核の一層の活発な研究を促すものであり，著者が自立して研究活動を行うのに必要な高度の研究能力と学識を有していることを示している。従って，村山卓提出の論文は博士（理学）の学位論文として合格と認める。